Low Cost Microstrip Filters and Mixers at 43GHz

Steve Williamson and Andy Dearn*

Introduction

Microwave Integrated Circuits (MICs), using discrete devices assembled onto a printed microstrip substrates were originally used at low microwave frequencies. They proved extremely successful, offering reduced size, weight and cost coupled with improved electrical performance, production uniformity and reliability [1]. However, many problems were encountered when the first attempts were made, to use this technique at mm-wave frequencies [2]. Microstrip circuits suffered from increased radiation losses, dispersion, unwanted coupling and discontinuity effects. The parasitic effects associated with the circuit assembly also caused problems and increased the production spread of performance.

These problems have been addressed over time; thinner substrates can be used to allow operation at mm-wave frequencies with reduced dispersion and radiation losses. Parasitics can be minimised and unnecessary discontinuities avoided. For unavoidable discontinuities, more accurate models are now available and accurate simulation of their effects is possible. MIC technology is now a proven technique for the fabrication of mm-wave circuits [3, 4].

This paper details the design, fabrication and measurement of MIC based mixers and microstrip filters operating at 43GHz.

Substrate fabrication

In order to manufacture the filter and mixer at a low cost, PTFE/random glass fibre substrate material was chosen. A low dielectric constant of 2.2 was selected (Rogers RT Duroid®/5880) to avoid fine line and tolerancing problems. A thin substrate height (0.005") was chosen to reduce the dispersion and radiation losses at mm-wave frequencies. A brass backing was used to provide rigidity.

In order not to compromise the priority of low cost, it was decided that the minimum track and gap width which could be processed by standard methods was 100µm ± 10µm. In order to allow for the addition of components such as un-packaged MMIC's, which would require bond wire attachment, and beam-lead components, such as high frequency capacitors, the microstrip tracking on the PCB was plated with 3µm of nickle and a further 3µm of gold.

Coupled line filters

Coupled line filters can be designed to produce either a maximally flat or equi-ripple response, with the design procedure being well understood [5, 6]. They have inherent rejection at low frequencies and, for a filter centered on f_0, are not re-entrant until $3f_0$, $5f_0$, etc. The out of band attenuation achievable between these re-entrant frequencies can be of the order of 30dB or more. A disadvantage of these type of filters is that it is possible for very narrow spurious pass-bands to be created at $2f_0$, $4f_0$, etc. due to slight imperfections in the coupling element lengths.

At a given frequency, coupling is maximum for quarter-wave elements. Figure 1 shows the variation of coupling with substrate height for a pair of quarter-wave coupled lines at 43GHz, with the coupler separation limited to 100µm. It can be seen that the coupling reduces with substrate height. The result of this is that as the substrate height is reduced, the track separation required to realise a coupled line filter becomes smaller. Thus the trade-offs between substrate height, minimum coupling gap and overall loss must be addressed to gain the required filter performance.

* The authors are with Plextek Communications Technology Consultants, London Road, Great Chesterford, Essex. CB10 1NY. Tel: +44 (0)1799 533200 Fax: +44 (0)1799 533201

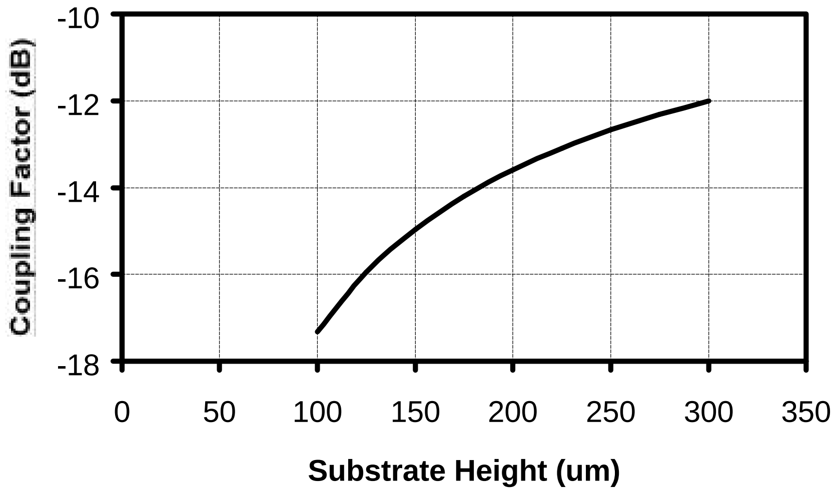

Figure 1 : Variation of coupling factor against substrate height.

Figure 2 is a photograph of the coupled line filter. As an indication of size, the 50Ω lines at the input and output are 370μm wide, whilst the first coupling gap is 100μm wide. The coupling elements in the filter are 1290μm long.

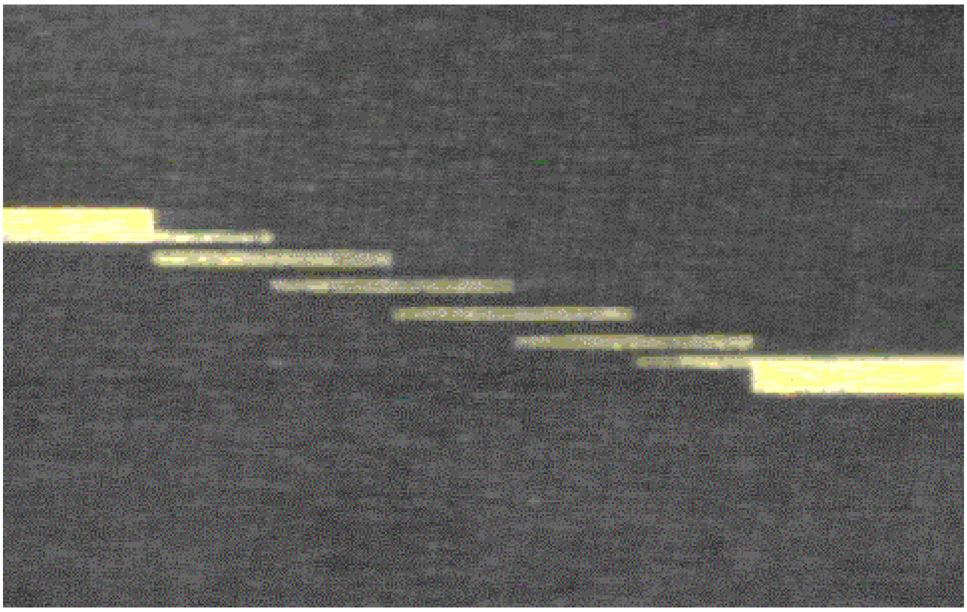

Figure 2 : Photograph of 43GHz coupled line filter.

The simulated performance of this filter is shown in figure 3, with the measured results in figure 4. The simulated results shown compare well with the measured results, indicating that the modelling of the filter took into account all necessary parasitic effects and that the manufacturing process is well controlled.

The measurements were performed in a test fixture with a TRL calibration, placing the measurement reference planes at the center of the substrate tile. The insertion loss of a 50Ω line the same length as the filter (0.12dB) must therefore be taken into account. This gives a measured insertion loss of 2.2dB at 43GHz compared to a simulated loss of 3.5dB. The slight difference is attributed to slight under etching of the lines decreasing the coupler gaps and increasing the coupling factor between them.

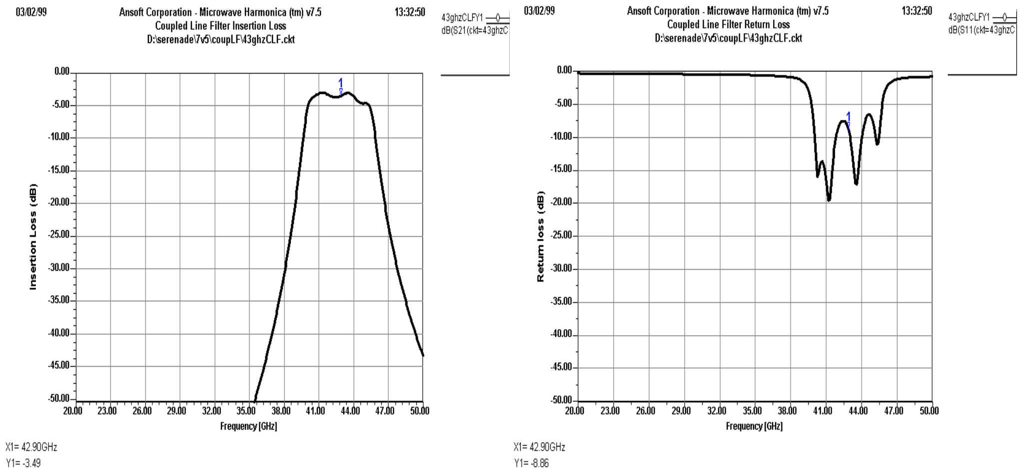

Figure 3 : Simulated S21 and S11 for the coupled line filter.

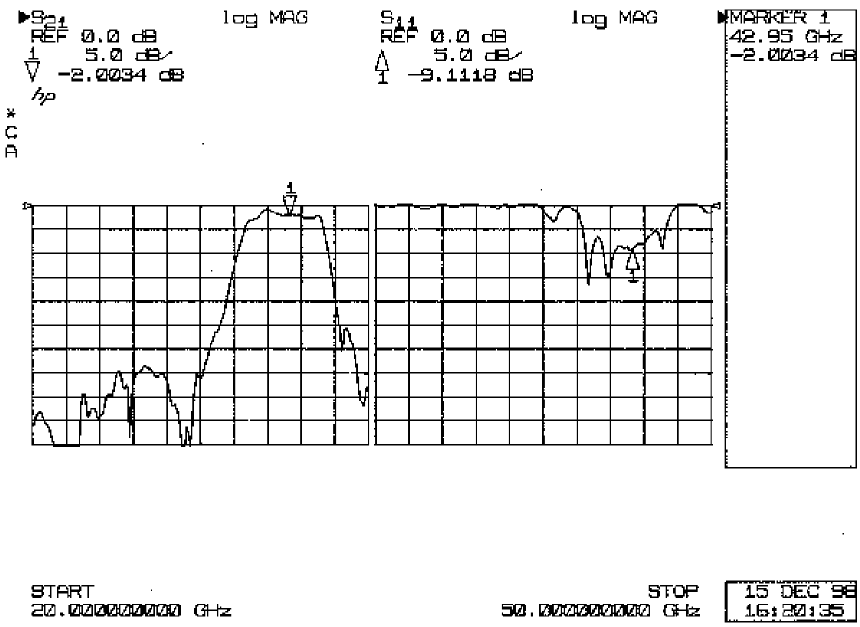

Figure 4 : Measured S21 and S11 for the coupled line filter.

Line and stub filters

The line and stub (LAST) type filters were derived in an effort to try and realise a filter with lower loss than the coupled line filters. The major problems with coupled line filters are the track and coupling gap widths being limited to 100µm, when the optimum design calls for dimensions less than this, forcing compromises in the filter design.

With these factors in mind the LAST type filter was created as a bandpass structure using microstrip elements. Bandpass filters require shunt inductors and are normally realised by the use of short circuit stubs. However, a through substrate via at 43GHz has a fairly high inductance, around 0.2nH on this material, thus quarter-wave radial stubs were used to acheive a low inductance short circuit at the ends of the inductive elements.

Figure 5 is a photograph of the LAST type filter. As an indication of size, the open circuit line on the top right of the main structure is 285μm by 2840μm.

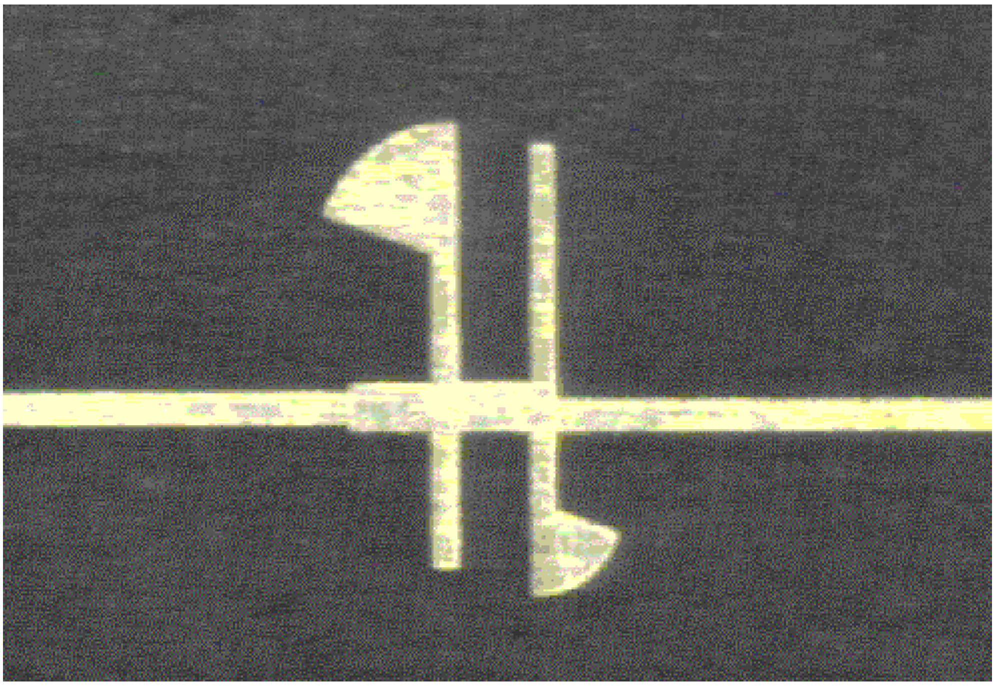

Figure 5 : Photograph of 43GHz line and stub filter.

The LAST type filter simulated performance is shown in figure 6, with the measured results shown in figure 7. Both the simulated and measured insertion loss of the LAST type filters were lower than that of the coupled line filter, being 0.3dB and 0.83dB respectively. The out of band attenuation was poor, being no better than 10dB to 15dB, but the notches achieved around 40dB of attenuation. These notches allow this structure to be used as a low loss, image reject filter.

The return loss of this filter was better than 20dB at 43GHz compared with little better than 9dB for the coupled line filter.   As a natural consequence of the construction of the LAST type filter, it has very poor low frequency rejection as there is always a straight through path. Also, the re-entrant responses for this type of structure are closer to the required passband and more numerous than those of a coupled line filter. The limited out of band rejection restricts the applications of this filter type. Its main advantages are low insertion loss and simple structure.

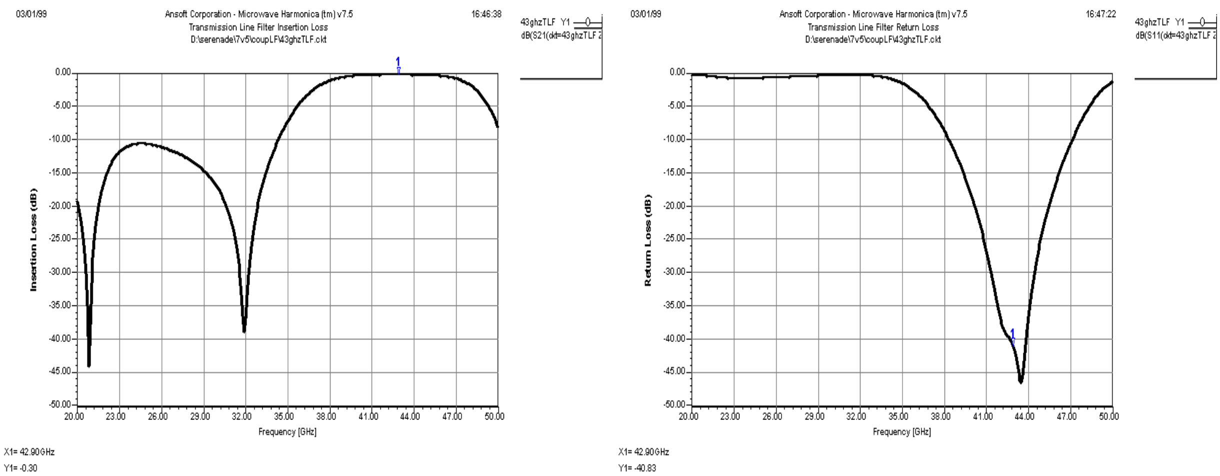

Figure 6 : Simulated S21 and S11 for the LAST type filter.

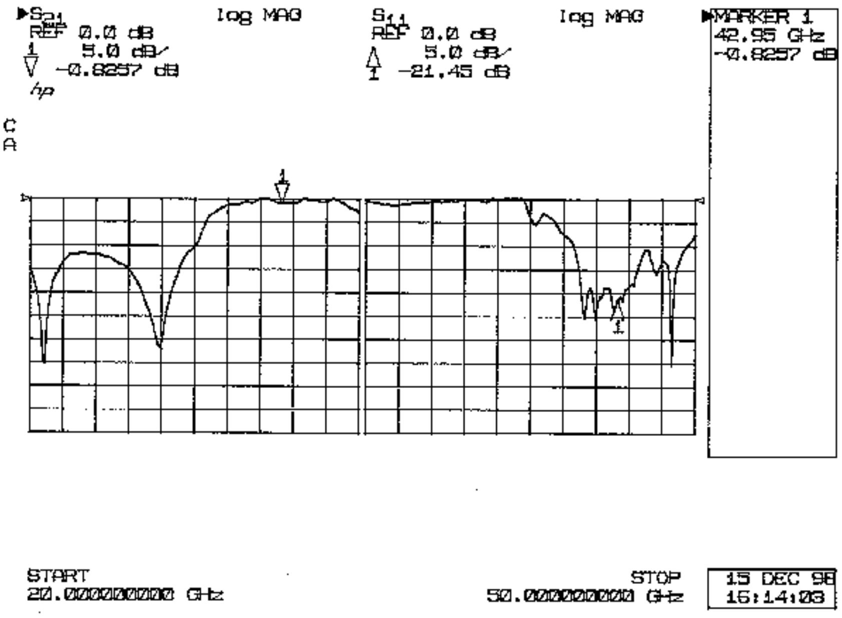

Figure 7 : Measured results for the LAST type filter.

Mixer

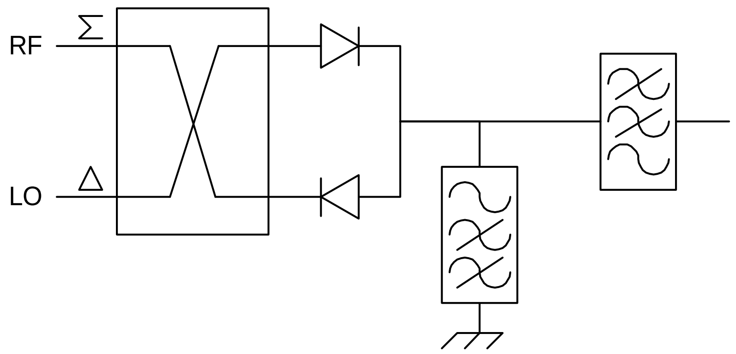

Figure 8 : Mixer schematic.

The mixer is a balanced type using a 180° hybrid as shown in figure 8. The hybrid is formed from a branchline coupler (90°) with an additional quarter-wave length of microstrip transmission line in the delta path. The diodes are flip-chip mounted mm-wave diodes from Alpha Industries (DMK2790), and are used un-biased. RF short circuits are provided, at the common port of the tuner diodes, by radial stubs. The low-pass filter is of distributed series-L/shunt-C form.

The flip-chip diodes were mounted using silver-loaded epoxy. The circuit was designed to operate at 43GHz RF, 38GHz LO, 5GHz IF, requiring a nominal LO power of +10dBm. The particular mixer configuration is reciprocal, in that it can be utilised as either an up-converter or down-converter. A photograph of this mixer is shown in figure 9.

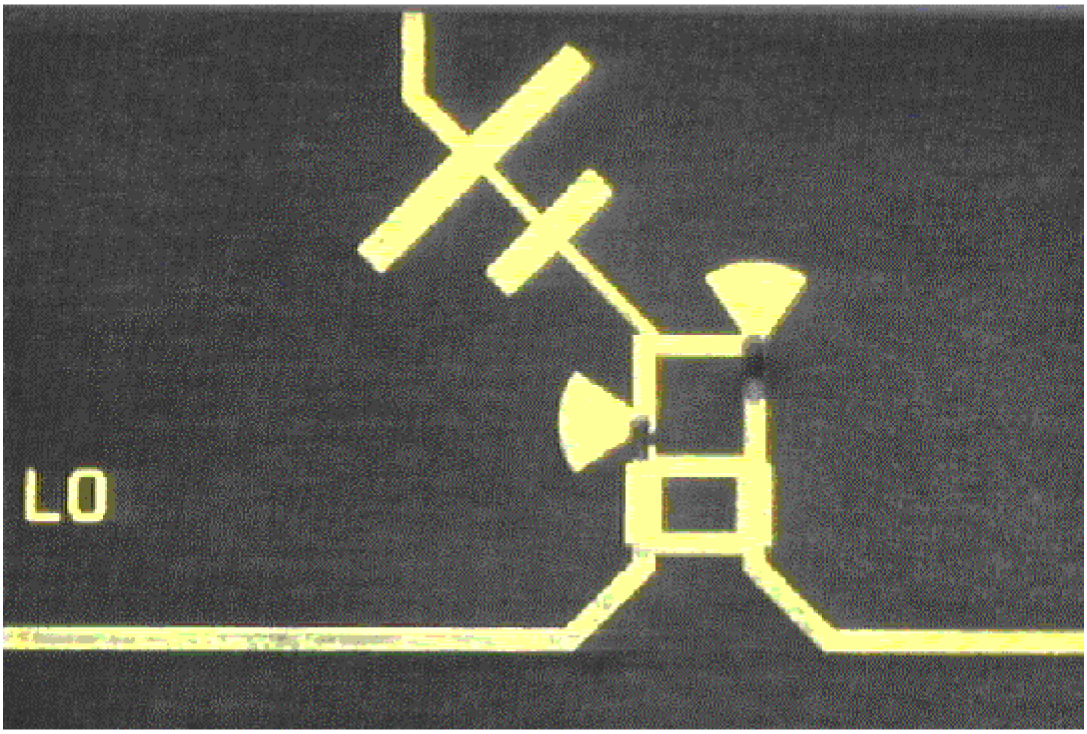

Figure 9 : Photograph of 43GHz mixer.

Figure 10 shows a Harmonic Balance Simulation of the 43GHz mixer, in down-convert mode. The applied LO is +10dBm at 38GHz. The RF input is at –10dBm, resulting in 9.5dB of conversion loss.

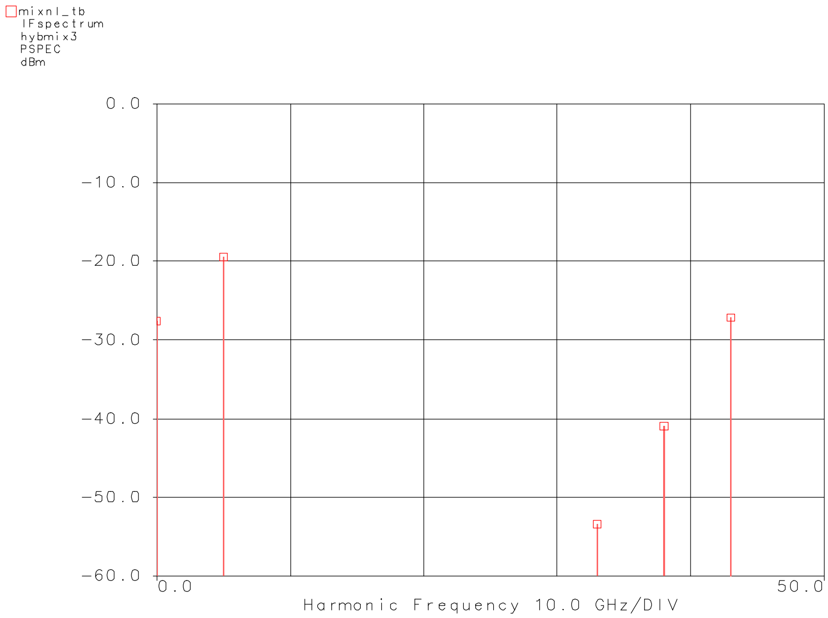

Figure 10: Mixer Simulation

The mixer was measured in a Universal Test Fixture from Anritsu with V connectors. Figure 11 shows conversion loss performance at 43GHz RF, with varying LO power. The agreement is within 2dB for all LO power levels.

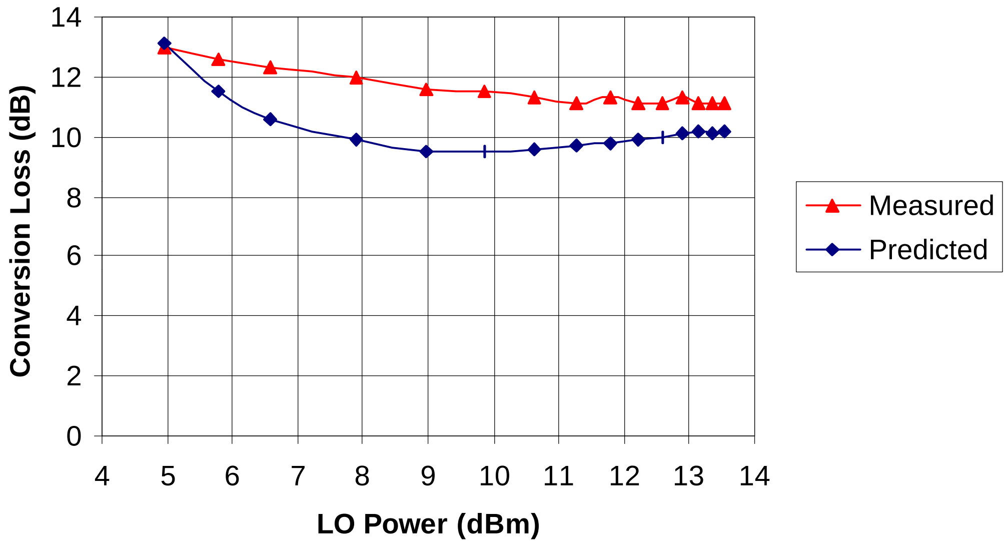

Figure 11 : Measured vs. simulated mixer performance.

Figure 12 shows the result of applying a two-tone signal to the input of the mixer. The output referred third order intercept (TOI) is –3.9dBm [given by -34dBm + (57.8dB/2) + 1.2dB (cable loss) = -3.9dBm]. Therefore the input referred TOI is +7.6dBm.

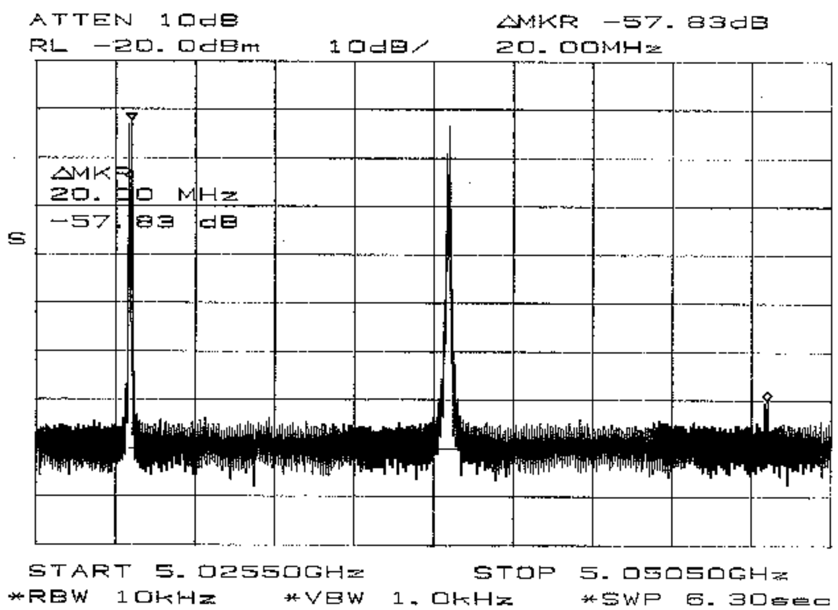

Figure 12 : IF output of 43GHz mixer with two-tone input.

Summary

This paper has shown a technique for fabricating mm-wave filters and mixers on a low cost PTFE substrate. These designs can be implemented without the use of via holes or restrictive etching dimensions and tolerances, whilst achieving good performance. The coupled line filter offers good rejection performance over wide frequency ranges, whereas the LAST type filter offers rejection at particular frequencies whilst achieving a lower insertion loss in the passband. The mixer is a balanced passive design offering a conversion loss of 11.5dB and an input referred TOI of +7.6dBm for an LO power of +10dBm. A combination of the filter and mixer designs can be utilised to provide a simple up or down-convertor with good attenuation of unwanted products such as the image frequency.

References

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